SOCIAL SCIENCES

Individual solutions to shared problems create a modern tragedy of the commons

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Alone and together, climatic changes, population growth, and economic scarcity create shared problems that can be tackled effectively through cooperation and coordination. Perhaps because cooperation is fragile and easily breaks down, societies also provide individual solutions to shared problems, such as privatized healthcare or retirement planning. But how does the availability of individual solutions affect free-riding and the efficient creation of public goods? We confronted groups of individuals with a shared problem that could be solved either individually or collectively. Across different cost-benefit ratios of individually versus collectively solving the shared problem, individuals display a remarkable tendency toward group-independent, individual solutions. This "individualism" leads to inefficient resource allocations and coordination failure. Introducing peer punishment further results in wasteful punishment feuds between "individualists" and "collectivists." In the presence of individual solutions to shared problems, groups struggle to balance self-reliance and collective efficiency, leading to a "modern tragedy of the commons."

INTRODUCTION

Throughout history, humans have provided for individual needs by establishing public goods such as armies and law enforcement, public education and social security, and public transportation. Likewise, humans can collectively fight the threats of climate change and the decline of scarce resources such as fossil fuel and fresh water (*1*–*5*). Yet, creating and sustaining public goods and shared solutions is challenging: They require cooperation that can quickly deteriorate in the absence of social preferences (*6*, *7*), reciprocity (*3*, *4*, *8*), and norm enforcement (*9*–*13*).

Perhaps because cooperation is inherently fragile, societies often provide individual solutions to shared problems. Privatized security (e.g., gun ownership) competes with a publicly funded police force, private education competes with public schooling, and transportation by car is an individual solution to the shared need for mobility. Theoretically, the availability of individual solutions alters the cost-benefit ratio of cooperation and the need for reciprocity, two core mechanisms underlying human cooperation and public goods provision (*3*, *4*, *8*). Yet, standard theory on public goods provision does not capture whether and how individual solutions influence collective action problems. As a result, we poorly understand how individual solutions to shared problems influence the human inclination for cooperation and coordination.

Creating individual solutions for shared problems decreases the individuals' immediate codependence on groups (*14*–*19*) and allows individuals to avoid the possibility that their cooperation is exploited by group members who do not contribute enough ("free riders") (*15*, *20*, *21*). To illustrate this situation, imagine a small village facing a flood that threatens the welfare of all group members. Villagers can join forces and build a dam that protects the village, including those villagers who did not contribute personal resources. Hence, the collective solution shares the property of a public goods dilemma; it is exploitable by free riding. However, imagine that each villager can also use his or her personal resources to build a dam around his or her own home, which saves the home owner but not the fellow villagers. Although this individual solution may be costlier than collectively solving the problem, it protects the individual against exploitation and the risk that the collective solution fails.

In two experiments, we confronted participants with this novel collective action problem in groups of four (Fig. 1). We show that, when individual solutions to shared problems are available, humans display a strong tendency toward self-reliance that creates, in turn, a "modern tragedy of the commons"—the inefficient allocation of resources by solving shared problems individually. Furthermore, we show that norm enforcement through peer punishment, which can sustain cooperation in classic public goods provision problems (*9*–*13*), exacerbates rather than mitigates this modern tragedy of the commons.

In our experiments, each group member was endowed with 10 resource points (RPs) for 10 rounds (100 RPs, in total). In each round, group members had to allocate their RPs to their individual pool, a shared public pool, or keep any amount for themselves (Fig. 1A). The RPs invested in the individual pool and shared public pool accumulated over rounds. After the 10th and final investment round, a participant would keep any resources not invested if the participant allocated enough resources to her individual pool to reach a predefined individual target. She would also keep her remaining resources if the group collectively allocated enough resources to the public pool to reach a predefined public target (Fig. 1B). If group members did not reach either their private or the public target in time, they lost everything. After each round, each group member observed the allocation decisions of the other group members and was informed about the so far accumulated RPs in their own individual pool and the shared public pool. Hence, participants were confronted with a dynamic collective action problem in which they had 10 rounds to invest enough resources into two conflicting solution strategies to prevent losing their remaining RPs.

Across five blocks of decision-making, we manipulated the cost-benefit ratio of the collective versus individual solution by changing the relative costs of the individual and public targets. The cost of the collective solution (c_c) was fixed to 160 RPs. Hence, if each group

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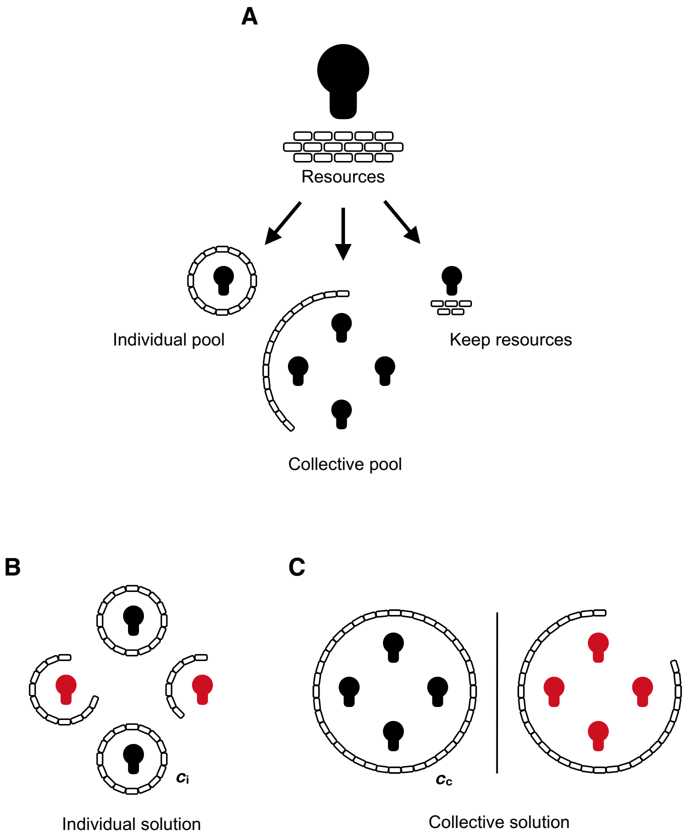

Fig. 1. (In)dependence dilemma. Group members face a shared problem that they have to solve in a given time. (**A**) They can either individually or collectively solve the problem by investing resources into an individual pool or a collective and shared pool, respectively. (**B**) Individually solving the problem costs c_i and saves the individual from losing all of his or her remaining resources. Collectively solving the problem saves all group members for a cost of c_c, where $c_c >> c_i$. (**C**) The collective solution is exploitable by free riding. Furthermore, the coexistence of collective and individual strategies can lead to coordination failure and wasted resources.

member would invest 40% of their points to the public pool, then the group would be saved. The cost of the individual solution (c_i) was either 80, 70, 60, 50, or 40, leading to varying cost-benefit ratios of individualism $i = c_i/(c_c/n) = \{2.0, 1.75, 1.5, 1.25, 1.0\}$.

If the cost-benefit ratio is high, then participants are relatively dependent on group efforts and collective action, similar to societies that heavily depend on direct reciprocity (such as hunter-gatherer groups). Under the highest codependence level ($c_i = 80$; $c_c = 160$; $i = 2$), efficiently coordinating on the public solution would save two times as much resources compared to individually solving the problem. With a decrease in i, participants become relatively more independent from their group by gaining access to affordable individual solutions to shared problems, similar to modern societies. Note that, under $c_i = 40$ ($i = 1$), there is no efficiency gain from coordinating on the public solution for the group, since the individual solution is as affordable as the public solution (assuming that group members contribute equally).

RESULTS

Transitioning from group dependence to independence, individuals switched from collectivism to self-reliance (random-effects regression, $P < 0.001$; Fig. 2A). Under high codependence ($i = 2$), 80% of the group members collectively solved the problem, without the need of any formal institutions or norm enforcement. Under low codependence ($i = 1$), on the other hand, 99% of the group members solved the problem individually.

Across codependence levels, groups frequently failed to coordinate on the more efficient collective solution. Instead, participants opted for individual problem solving and were willing to pay a high premium for self-reliance (Fig. 2B). On average, groups switched from the individual to the collective solution when $i > 1.7$. In other words, only when efficient coordination would save more than 70% of the resources groups started to collectively solve the problem. Wasted resources and decline in group welfare followed an inverted U-shape relation across codependence levels (random-effects regression, $P < 0.01$; Fig. 2C). Hence, especially in situations of intermediary codependence, a new type of the tragedy of the commons emerges: When group members are relatively independent but would still benefit from collective action, a conflict between individualistic and collective strategies led to inefficient solutions to shared problems.

Coordinating on the public solution is far from trivial. Because of the large strategy space, there are many theoretical Nash equilibria in which rational agents find a collective solution (see the Supplementary Materials for details). Choosing individual solutions to shared problems may, hence, be driven by the risk of coordination failure that is inherently part of the collective solution in our setting (working in groups is risky and success is uncertain, while working alone is safe). Furthermore, while free riding on public contributions can lead to the highest potential payoff, it can also result in losing all remaining RPs if other group members are not compensating the missing resources to reach a public solution. Consequently, we observe rather low levels of free riding across the independence levels (Fig. 3A). Choosing the individual solution could also be driven by the fear of exploitation and free riding. Under the highest codependence ($i = 2$), 40% of the participants contributed more than the fair share to the public pool ("altruists"), while 26% contributed less than their fair share to the public pool and did not attempt to reach their individual threshold either ("free riders"). In the transition to group independence, the collective action problem transformed from a public goods dilemma, in which some group members are forced to offset the costs of free riding, to a purely individual problem-solving task (Fig. 3A).

Individuals who contributed less than their fair share to the public solution under high interdependence were not systematically more or less likely to switch to an individualistic strategy compared to individuals who contributed their fair share or more when the cost-benefit ratio of individualism decreased (Markov chain transition estimates, $P = 0.43$; Fig. 3B). In other words, knowing the behavior of an individual under high codependence did not allow us to predict when the individual would switch to an individualistic strategy under decreasing codependence. This suggests that individualism cannot simply be equated to selfishness, as suggested previously (*6*, *7*), but rather emerges as a distinct strategy when the need for reciprocity declines. Furthermore, an independent measure of participants' social preferences that was obtained after the experiment (estimating the degree of nonstrategic prosociality of individuals through a series of allocation decision) was correlated with public and withheld contributions but not with investments to the individual pool. The more the participant was

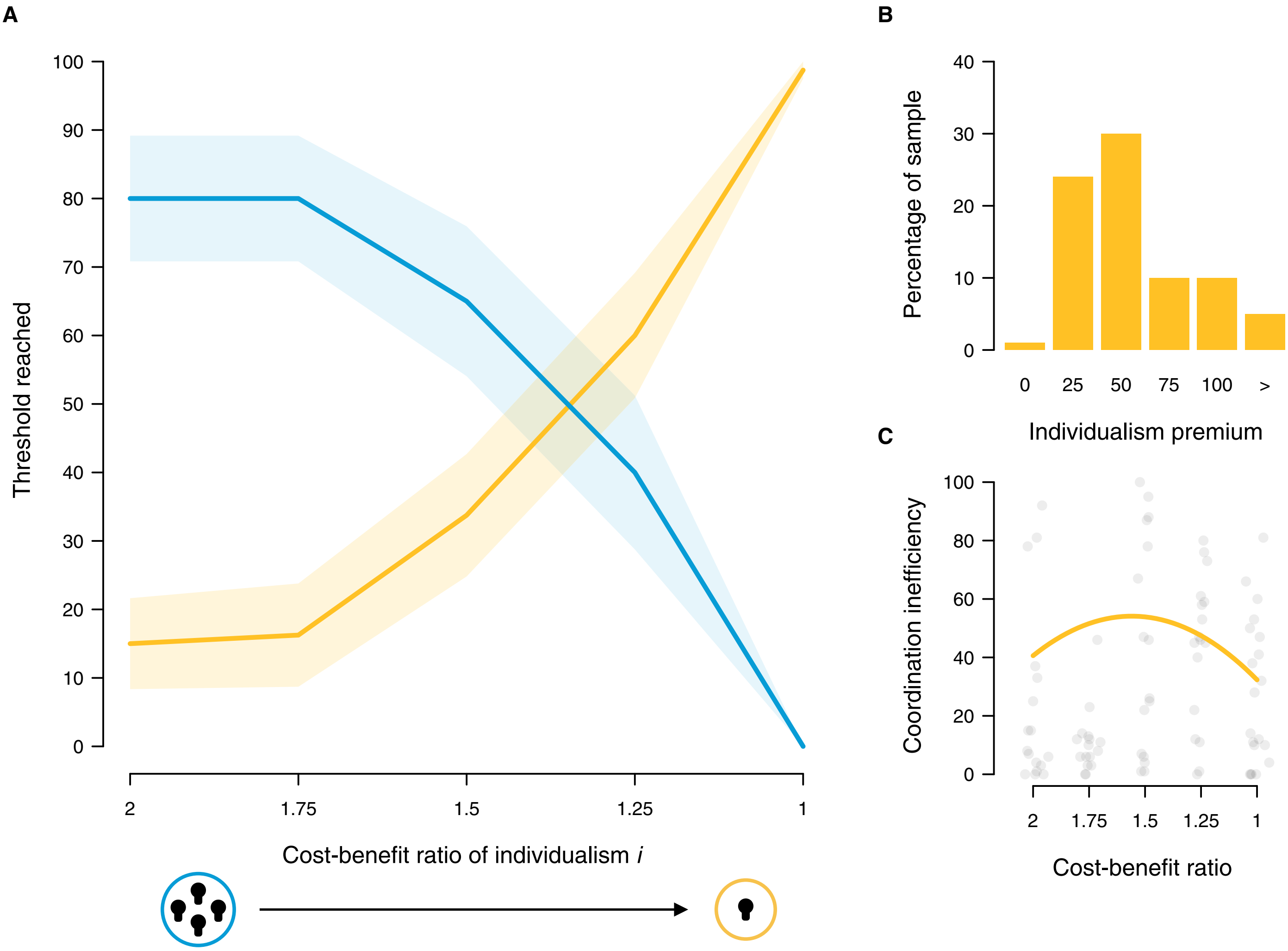

Fig. 2. From collective action to individualism. (A) When transitioning from high ($i = 2$) to low codependence ($i = 1$), groups increasingly switch from collectively (blue) to individually (yellow) solving the problem. **(B)** Many participants are willing to pay for individually solving the problem, even when it exceeds the costs of an efficient collective solution by 25 to 100%. **(C)** The coexistence of individual and public solutions leads to an inverted U-shaped waste of resources across dependence levels. In particular, in intermediary dependence situations, groups overinvest resources compared to the efficient group coordination benchmark of 160 RPs.

willing to sacrifice her own resources to help another unknown person in this measure (degree of prosociality), the more RPs the participant contributed to the public solution ($r = 0.17$, $P = 0.03$) and the less the participant kept for herself ($r = -0.18$, $P = 0.02$). Yet, the degree of prosociality was uncorrelated with investments in the individual pool ($r = 0.00$, $P = 0.99$). Knowing the participant's other-regarding concerns did not allow us to predict her likelihood to opt for the individual solution.

Even when the collective solution could save two times as much resources, 15% of participants still followed an individualistic strategy, and across all dependence levels, groups could have saved 45 RPs on average if they would have coordinated on the public solution. In classic public goods dilemmas, peer punishment has been shown to foster group contributions by enforcing norms of cooperation (*9*–*13*). In a second experiment, we therefore investigated whether peer punishment could also help to solve coordination conflicts between individualism and collectivism. Groups engaged in the same (in)dependence dilemma but, after each round, could assign up to five punishment points (PPs) to each other group member. Each assigned PP reduced final earnings of the punisher by one unit but reduced the final earnings of the punished by three units.

Across codependence levels, peer punishment indeed increased the propensity to collectively rather than individually solve the problem (random-effects logistic regression, $P = 0.04$; Fig. 4A). However, punishment did not reduce free riding (random-effects logistic regression, $P = 0.72$; Fig. 4B). Instead, punishment was mainly aimed at "individualists" (random-effects regression, $P < 0.001$) who, in turn, punished altruists (random-effects regression, $P = 0.01$). Note that free riders, while contributing less than the fair share and less than cooperators and altruists to the collective solution, still contributed more to the public solution than individualists who focussed on their individual target instead. In this regard, it makes sense that altruists focus their punishment mainly on individualists who, from their perspective, follow an incompatible strategy to the shared problem. However, this punishment pattern, resulting from the conflict between self-reliance and collective efficiency, led

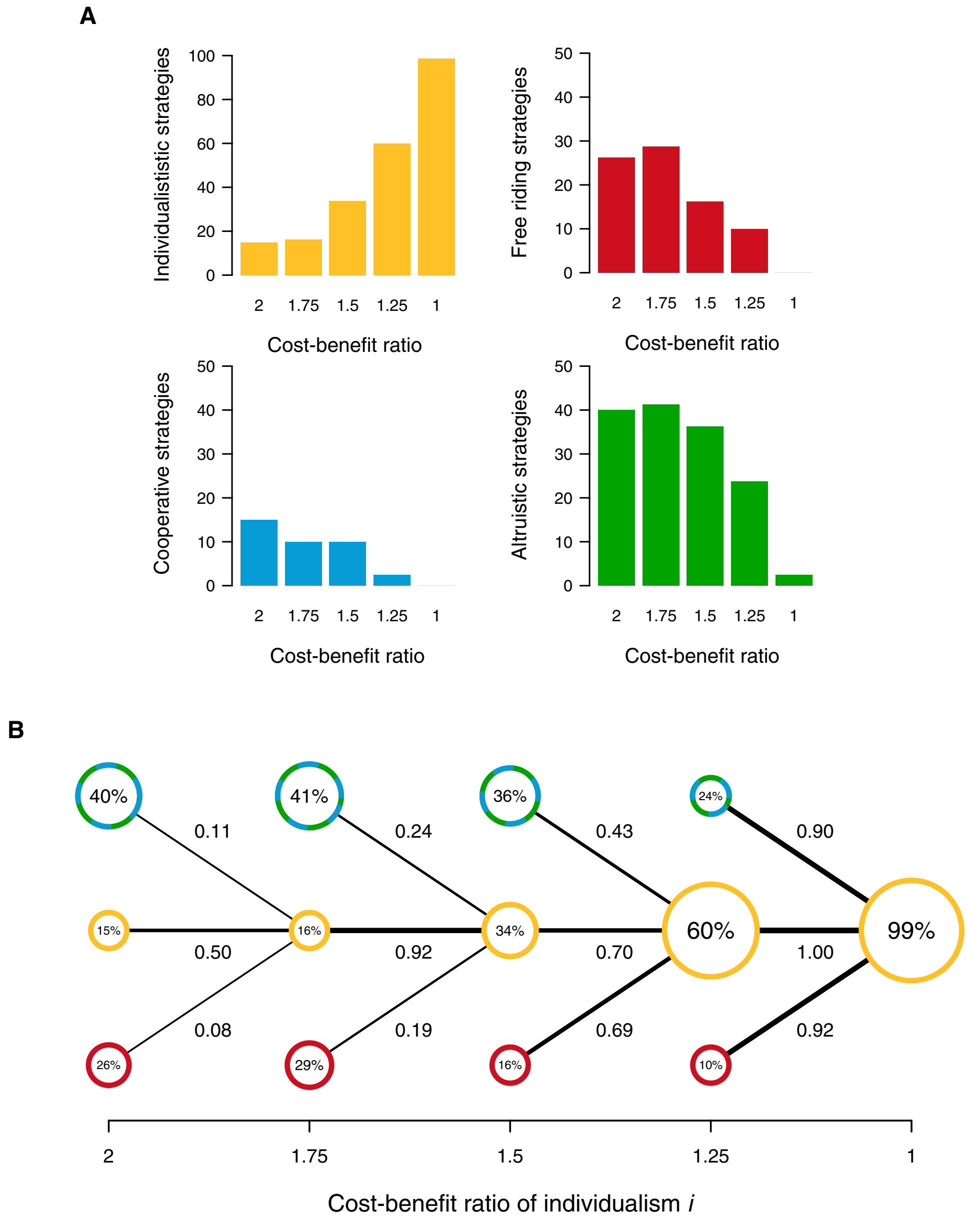

Fig. 3. Strategy shifts. (**A**) Under high codependence ($i = 2$), some group members are willing to pay more than their fair share to the public solution (altruistic strategy, green) to offset the cost of free riders who contribute less than their fair share and, at the same time, do not attempt to solve the problem individually (free riding strategy, red). Others either contribute their fair share (cooperating strategy, blue) or avoid the free rider problem by opting for individually solving the problem (individualistic strategy, yellow). With decreased codependence, the share of participants who individually solve the problem increases. (**B**) People who followed a cooperative/altruistic strategy are as likely to switch to individualism, as people who followed a free riding strategy. Numbers indicate the average transition probability based on Markov chain estimations when individualism becomes more affordable.

to an overall decrease in group welfare (random-effects regression, $P = 0.014$). Together, these results question the effectiveness of unregulated peer punishment in modern tragedies of the commons, in which individual solutions to collective problems are available.

DISCUSSION

For most of human history, cooperation has been a necessity. Hunter-gatherer societies facing harsh environments from the Inuit at the Polar Circle to the Mbendjele in the Congo are highly codependent and show a remarkable degree of cooperation and egalitarianism (*17*, *22*–*25*). This mimics our finding that, when individual solutions are too costly to pursue, groups endogenously manage to coordinate and solve the problem as a collective without much need for formal institutions.

The marked changes that came about with technical innovation and market economies (*26*, *27*) made reciprocal cooperation a possibility rather than a necessity. Studies have shown that individualism and valuing independence are worldwide on the rise and correlated with economic changes (*28*–*30*). We show that, in collective action problems, reduced codependence on others can lead to inefficient

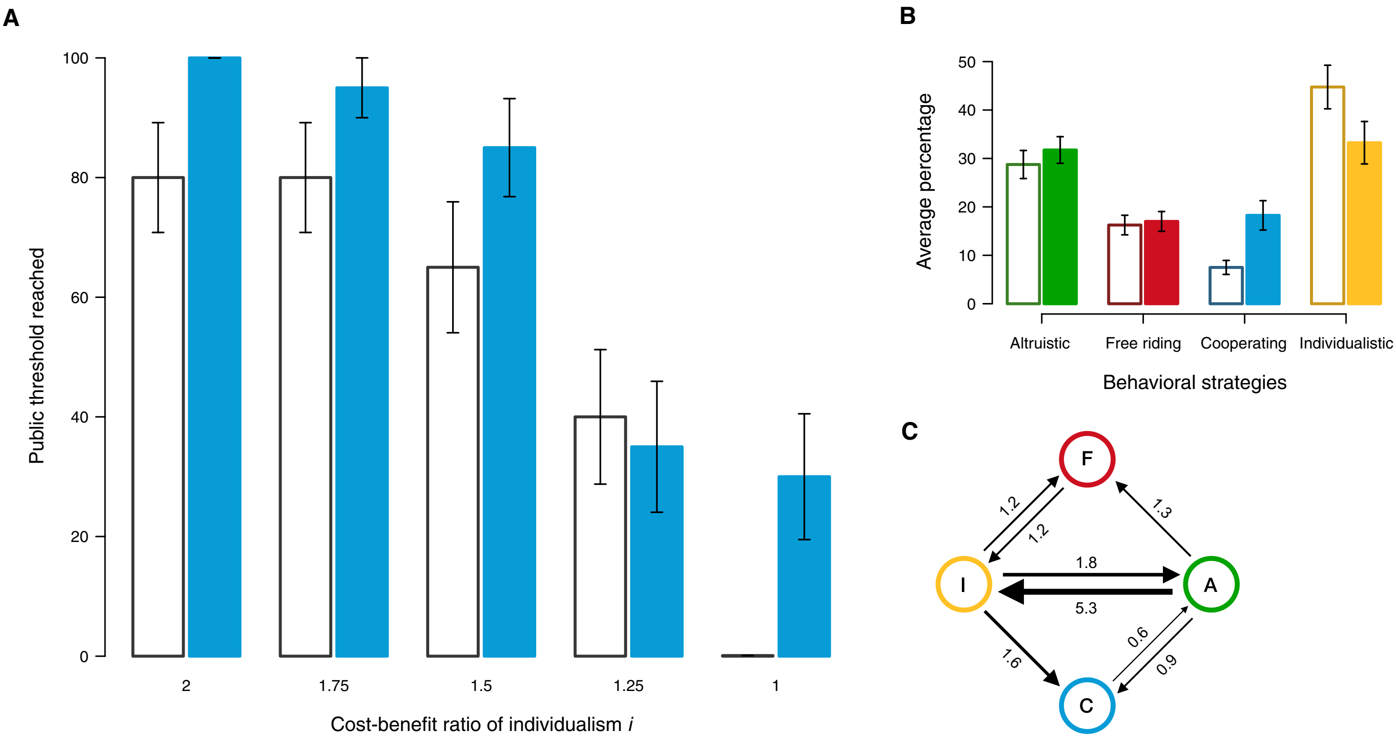

Fig. 4. Peer punishment enforces collective action. (**A**) Across codependence levels, peer punishment (solid bars) increases the propensity to solve the problem together, compared to baseline (open bars). (**B**) Peer punishment changes the average composition of strategies (open bars, baseline; solid bars, punishment). Cooperative strategies (blue) increase, while individualism (yellow) decreases. The frequency of free riding (red) and altruism (green) is, however, unaffected by peer punishment. (**C**) Peer punishment is mainly dealt by altruists (green) punishing individualists (yellow). Individualists are willing to sacrifice resources to punish altruists in turn. Free riders (red) and cooperators (blue) are mainly left alone and refrain from punishing others. Numbers indicate the average assigned PPs in one block.

allocation of resources and coordination failures due to (some) group members opting for independency rather than group cooperation.

Traditional measures such as peer punishments, which can attenuate the classic tragedy of the commons (*9*–*13*), appear to amplify rather than mitigate this coordination failure. Providing an unregulated peer punishment option as a mean to enforce cooperation norms rather led to punishment feuds between individualists and collectivists. Outside of the laboratory, societies that provide attainable individual solutions to shared needs may therefore have found other solutions to foster cooperation and coordination, such as centralized punishment institutions or establishment of stronger norms of cooperation and generalized reciprocity (*31*, *32*).

Choosing individual solutions over collective action might be driven by a fear of exploitation and pessimistic beliefs about the cooperativeness of others or by the risk that the collective solution is not reached. Arguably, conditional cooperators (with pessimistic beliefs in the cooperativeness of others) should favor individualistic solutions when they are affordable. Another interpretation is that people differ in their desire for being independent of social groups, regardless of their other-regarding concerns. The dynamic nature of our experimental design and the fact that the individual solution was safe while the collective solution required coordination and was risky do not allow us to cleanly disentangle individual motives. Yet, the results on strategy shifts across the interdependence levels and the results of individual's social preferences point to the possibility that a preference for self-reliance may be distinct from preferences for selfishness versus cooperativeness, opening up interesting avenues for future studies.

Contemporary societies face pressing shared problems such as underfunded public education and law enforcement and resource scarcity due to climate change and population growth. Here, we documented that a modern tragedy of the commons emerges when and because individual solutions to these shared problems are introduced. Whereas individual solutions allow individuals to inoculate themselves against exploitation, they can lead to a costly failure to coordinate collective action for the benefit of all and a wasteful punishment feud between those that favor self-reliance and those that favor collective efficiency. Whenever individual solutions to collective problems exist or are introduced, groups and societies need not only to contain the free rider problem but also to strike a balance between the ability of its members to abstain from collective action on the one hand and efficient public goods provision on the other.

MATERIALS AND METHODS

We tested a total of 160 participants in a computerized experiment at the University of Leiden. We obtained informed consent from all participants before taking part in the experiment. Participants were free to withdraw from participation at any time. Experiments were approved by the Psychology Research Ethics Board of the University of Leiden (file CEP17-1008/332). Participants were randomly allocated to groups of four (40 groups in total) and to the two experiments. After instructions and comprehension questions (see the Supplementary Materials), groups were confronted with the (in)dependence dilemma. Each group member received 10 RPs worth €0.80 in each round and could freely distribute these RPs among their individual pool and a shared public pool, keeping the remaining RPs for themselves. Across rounds, the RPs invested to their individual pool or the shared public pool accumulated. After the final round, participants knew that they had to reach either the public or their individual target to avoid losing all RPs that they kept for themselves. To reach the public target, the group's public pool had to contain at least c_c RPs after the 10th and final round. The cost for collectively solving the problem was fixed to $c_c = 160$ RPs (i.e., 40% of each group member's endowment). To reach the individual target, the group member's individual pool had to contain at least c_i RPs after the 10th and final round. The cost for individually solving the problem varied across five blocks with $c_i = 40$, 50, 60, 70, and 80. The block order was counterbalanced across groups. After each round, participants saw the so far accumulated RPs in the public pool, their individual pool, and how other group members allocated their resources in the last round. The second experiment proceeded identically, except that each investment stage was followed by a peer punishment stage. In this stage, participants were able to assign up to five PPs to each other group member. Each assigned PP would reduce the final earnings of the punisher by one RP and the final earnings of the punished by three RPs. After each punishment stage, participants received feedback on how many PPs each group member received in total. One block of the experiment was randomly selected for payment, and participants received any remaining RPs in euro (on top of a fixed lump sum payment of €6.50 and earnings from the slider measure) if they reached either their individual or the public target in the selected block. After the experiment, participants answered demographic questions (such as age, gender, and field of study) and filled out the incentivized six-item social value orientation slider measure (*6*). In this task, participants have to make six decisions on how to allocate points between themselves and an unknown other person. Points can be allocated self-servingly or prosocially (sacrificing points to benefit the other person), allowing us to estimate the degree of other-regarding concerns (i.e., social preferences).

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/5/4/eaau7296/DC1

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